Fire Technology, 53, 649–672, 2017

Manufactured in The United States
DOI: 10.1007/s10694-016-0586-2

Guidance for the Model User on Representing Human Behavior in Egress Models

Erica D. Kuligowski, National Institute of Standards and Technology, Gaithersburg, MD, USA*
Steven M. V. Gwynne, National Research Council Canada, Ottawa, Canada
Michael J. Kinsey, Arup, London, UK
Lynn Hulse, University of Greenwich, London, UK

Received: 14 September 2015/**Accepted:** 22 March 2016

Abstract. Structures are currently designed and constructed in accordance with prescriptive and performance-based (PBD) methodologies to ensure a certain level of occupant safety during fire emergencies. The performance-based approach requires the quantification of both ASET (Available Safe Egress Time) and RSET (Required Safe Egress Time) to determine the degree of safety provided. This article focuses on the RSET side of the equation, for which a fire protection or fire safety engineer would use some type of egress modelling approach to estimate evacuation performance. Often, simple engineering equations are applied to estimate the RSET value. Over time, more sophisticated computational tools have appeared—that go beyond basic flow calculations; e.g. simulating individual agent movement. Irrespective of the approach adopted, appropriate and accurate representation of human behavior in response to fire within these approaches is limited, mainly due to the lack of a comprehensive conceptual model of evacuee decision-making and behavior during fire emergencies. This article initially presents the set of behavioral statements, or mini-theories, currently available from various fire and disaster studies, organized using the overarching theory of decision-making and human behavior in disasters. Once presented, guidance is provided on how these behavioral statements might be incorporated into an evacuation model, in order to better represent human behavior in fire within the safety analysis being performed. The intent here is to improve the accuracy of the results produced by performance-based calculations and analyses.

Keywords: Egress model, Performance-based design, Human behavior, Fires, Required safe egress time, Egress, Modeling

1. Introduction

For a building to be constructed and occupied, the fire protection/safety engineer must first establish that the building provides a sufficient level of safety during a

* Correspondence should be addressed to: Erica D. Kuligowski, E-mail: erica.kuligowski@nist.gov

fire incident. Buildings are currently designed and constructed in accordance with prescriptive and performance-based methodologies to ensure this level of safety.

Prescriptive approaches rely on the application of a predetermined set of rules that, if employed, typically allow the design to be *deemed* safe [1]. However, the achieved degree of safety is not always apparent. In contrast, performance-based designs (PBD) rely on a quantitative assessment of the fire and evacuation performance levels achieved. This approach requires the quantification of both ASET (Available Safe Egress Time—the time before conditions become untenable) and RSET (Required Safe Egress Time—the time for the population to get to a place of safety, as represented by the required safe egress time). These are then compared to establish whether there is sufficient time, given a margin of safety, for the population to reach safety before conditions become untenable. In recent years, PBD has become increasingly popular given that it can be applied to more unorthodox and complex structures (e.g. entertainment complexes [2, 3], heritage sites [4], shopping malls [5], etc.) and provides an evidence-based approach in assessing performance. This article focuses on the RSET side of the equation, for which an engineer would use some type of egress calculation.

Often times, simple engineering equations are applied to estimate the RSET value. These equations do not explicitly represent many of the expected evacuee behaviors (e.g. information seeking), or the factors influencing them, and make simplified assumptions regarding performance. For example, the movement of the population is determined by the number of people in a space and the floor space available [6], with the population effectively behaving like a fluid travelling along a pipe. These equations are only able to provide aggregated results, such as overall performance levels, rather than detailed results and influencing factors. These simplified assumptions may *underestimate* the time for a population to reach safety, possibly reducing design safety levels [6].

Over time, more sophisticated computational tools have appeared [7]. These tools can often represent the evacuating population as individual agents (i.e. simulating the micro- as opposed to macro-level) and often more accurately represent the nature of the space, individual attributes and the loss of routes due to the incident [8]. These models have the potential for representing factors that influence agent behavior and the agent decision-making process [9]. However, these models generally simplify behavior during evacuations, if behavior is included at all; for instance, an empirical description of a behavior, both simplified and sequential in nature. Although current egress models now typically include *some* representation of the physical and behavioral aspects of evacuee performance, the representation of the physical aspects is still more complete. This is likely due to the more mature understanding of the physical processes involved in evacuation and the availability of more data; however, it is also influenced by a longstanding bias, from some, towards the physical and a belief that the behavioral process is less amenable to simulation [10].

To better represent human behavior in fire would require a comprehensive conceptual model of evacuee decision-making and behavior to be embedded within the engineering calculations or computational models. Previous efforts in conceptual model development have been made, primarily based on behavioral research/-

data from specific incidents [9, 10], focusing on certain aspects of the process [11], or providing a general overview [12, 13]. However, it is necessary to have a model that can be generalized to various types of fire incidents and be of sufficient scope and refinement.

In a companion article [14], a preliminary conceptual model of human behavior in fire was presented that encompassed behavioural data and theory from various types of emergencies, including fire incidents. This model takes the form of a set of behavioural statements comprising the primary elements of current understanding of evacuee behavior. The statements were distilled from articles and authoritative reports describing incidents, observations from within the field of evacuation analysis and human behavior in fire [10–12]. The companion article offered guidance for model developers on how these statements could be incorporated into egress models, to help advance the representation of behavioral aspects of evacuee performance. However, for a conceptual model to be truly effective, it must also be utilised by model users. The purpose of this article is to introduce users to the preliminary conceptual model and provide guidance on how it might be incorporated into *existing* evacuation calculations or computer models, in order to more accurately represent human behavior in fire within life safety analyses.

2. Human Behavior in Fires: Theory Development and RSET

Below are 28 behavioral statements comprising the preliminary conceptual model.[1] The statements consist of mini-theories on behaviors that can occur during an evacuation, the factors that influence these behaviors, and their outcomes. These statements have each appeared several times in the literature in some form—either as a finding from research or as an assumption in modelling analysis, or some combination of the two. Yet, until recently, these statements were isolated: distributed between publications and other sources and used occasionally (or in a piecemeal manner) in current egress analysis. Separately listed, they represent a disparate picture of human behavior during fire evacuation. However, this model was constructed based upon a theoretical framework of individual decision-making and response to emergencies—the Protective Action Decision Model, or PADM [15]. The PADM, which is based on over 50 years of empirical studies of hazards and disasters [16–20], provides a framework that describes the information flow and decision-making that influences protective actions taken in response to natural and technological disasters [15]. When organized into the PADM framework (see Table 1; Fig. 1), we move the field closer to a comprehensive theory of human behavior in fire.[2] As such, the statements are meant to be considered together rather than in a piecemeal manner.

[1] The number and presentation of these statements has evolved since an earlier presentation [14].

[2] This list is by no means exhaustive, but represents the key behavioral conventions that are identified, understood, and employed within model development and engineering practice to some degree of frequency.

Table 1
The Preliminary Conceptual Model of Human Behaviour in Fire

Phase	Behavioral statement
Pre-decisional processes	[1] Previous experience of false alarms or frequent drills can reduce sensitivity to alarm signals, inhibiting perception processes [21]
	[2] Some individuals exhibit hypervigilance that makes them particularly sensitive to certain cues [10]
	[3] Habituation, focus and stress can narrow the perceptual field, and thus, not all available cues will be internalized [22]
	[4] Sensory and cognitive impairments can inhibit the perception of cues [23]
	[5] Content and clarity of the cue matters. The more clearly presented, without jargon, the more likely it will be comprehended accurately [24]
[Stages 1 and 2] Assess situation/risk	[6] The precision, credibility, consistency, comprehensiveness, intensity and specificity of the external cues will affect the assessment of the situation and perception of risk [24]
	[7] Authority of the information source affects the perceived credibility of the information, and in turn the assessment of the situation and risk [25]
	[8] Normalcy bias and optimism bias are commonplace. In other words, people often think that nothing serious is taking place, and that nothing bad will happen to them, respectively [26, 27]
	[9] Training on and/or experience with a particular incident type may allow a similar incident to be defined more quickly by the evacuee [28]
	[10] The actions of the surrounding population can influence the internal processes of the individual [29]
[Stage 3 and 4] Protective action search and selection	[11] People tend to satisfice rather than optimize [30]
	[12] Pre-event commitment to a particular activity may cause individuals to decide against taking protective action [31]
	[13] Authority of the source… affects the perceived credibility of the action [25]
	[14] The actions of the surrounding population can influence the options of actions developed by the individual [29]
	[15] Gender can influence the selection of actions to protect property [10]
	[16] Social and authoritative roles, and social connections, can influence the selection of actions to help others [10]
	[17] Training and experience in previous fire/evacuation events can influence the search for and selection of a particular action or set of actions [28]

Table 1
Continued

Phase	Behavioral statement
[Stage 5] Protective action implementation	[18] The appearance of a route can influence its use [32, 33]
	[19] The presence of smoke does not always preclude the use of a route, but can influence movement along a route [34]
	[20] Training and experience may increase an individual's familiarity with the use of components/devices and subsequently improve their use [35]
	[21] People have different abilities that influence actions taken [23]
	[22] People seek information in situations where information is lacking or incomplete [10, 34, 35]
	[23] People engage in protective actions, including preparing to move to safety or helping to protect others from harm, before they initiate a movement towards safety. [34, 36] These actions can also occur while moving to safety
	[24] People move towards the familiar, such as other people, places and things [31]
	[25] People may re-enter a structure, especially if there is an emotional attachment to the structure, the contents and/or the inhabitants [34]
General	[26] People will behave in a rational AND altruistic manner; panic is rare [11, 34, 37, 38]
	[27] Evacuation is a social process, in that groups are likely to form during an evacuation [39]
	[28] Social norms (or rules) in place prior to a fire event form the basis of those employed during the event [40]

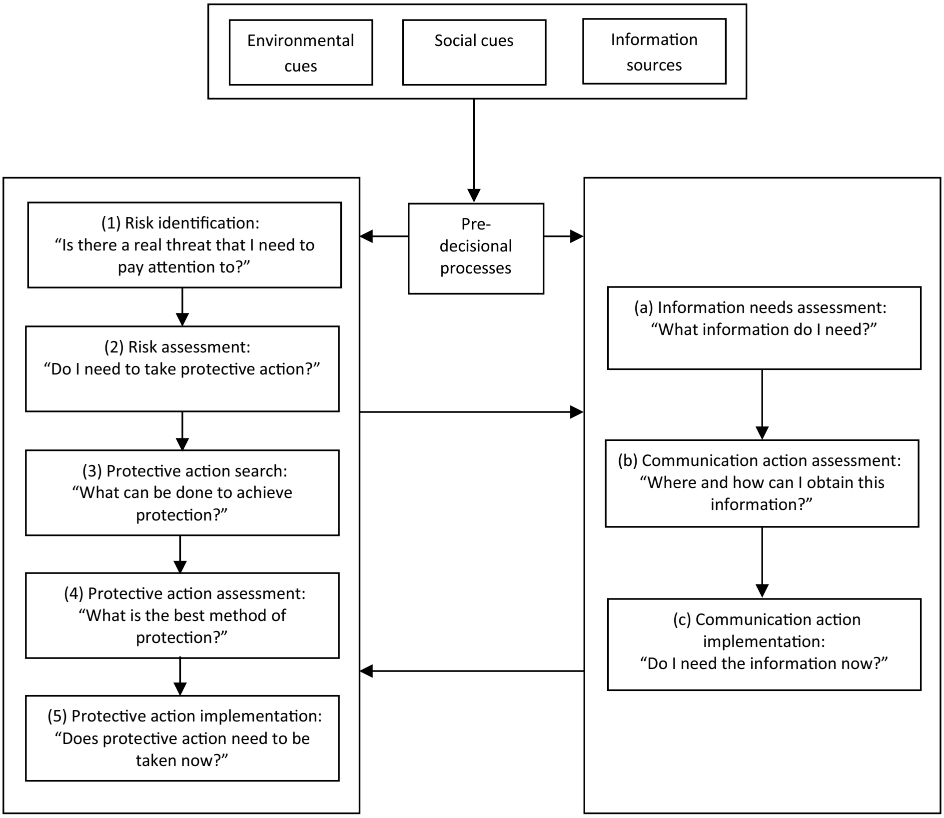

Fig. 1. The protective action decision model (Source—[15] redrawn from p. 47).

Some of the first questions this list might raise in users' minds is *why* must all these different behavioral aspects be taken into consideration when conducting a life safety analysis and, perhaps more vexingly, *how* might they be incorporated (indeed, they may be asking can all 28 behavioral statements really be incorporated)? There are currently over 60 different computer evacuation models available to assess evacuation performance [8, 41]. These range from hydraulic calculations that only produce aggregate results (e.g. overall evacuation time), to adaptive agent-based approaches where results can be collected at the agent level (e.g. distances travelled) as well as aggregate levels. The variety in the models available and the fact that none of them currently explicitly represent the full set of behavioural statements might make users sceptical regarding the "how?" question. Nevertheless, despite differing in many ways, most of the 60+ evacuation models employ four basic performance elements to calculate RSET. These elements are aspects of the model that users are required to manipulate, i.e., include input data for or initiate some default value, in order to calculate RSET. More specifically, these elements can be manipulated by the user to explicitly or implicitly account for most (or all) of the behavioural statements previously discussed. The following four performance elements are standard in most current computer-based evacuation models:

1. [Pre-Ev] Pre-evacuation time—the time for evacuees to initiate response and commence movement to a place of safety once an incident has started.
2. Physical movement characteristics [PMC] of the evacuating population—including travel speed (the unimpeded speed at which individual evacuees move towards a place of safety) and flow conditions (the relationship between speed/flow, population density and population size within a local area), both of which can be affected by group formation.
3. [RA] Route availability—the routes available to the evacuees.
4. [RU] Route usage/choice—the routes selected by the evacuees from those available or those of which the evacuee is aware.

In more advanced evacuation models, a fifth performance element can be added to the list: behavioral itineraries [BI]. The user can address evacuee delays before or during evacuee movement by assigning behavioral itineraries to evacuees or groups of evacuees. Behavioral itineraries are tasks performed during the pre-evacuation or movement phases of an evacuation, and are assigned usually by individual or group. The behavioral itinerary requires the definition of the locations visited during the evacuation and the time spent at these locations. The itinerary then implicitly represents evacuee behavior and the associated delays that are not directly associated with movement to a place of safety.

The above list of performance elements is limited, omitting a number of factors represented in particular models. This is intentional; the point being that there is at least a core set of elements on which the majority of evacuation models conform, elements which users can make choices about and control, and four out of these five elements are influenced by human behaviour. (Note: The route availability [RA] performance element is often determined by the fire scenario, rather than by the individuals and their behavior during evacuation). That means that, irrespective of the type of evacuation model used, there is mechanism for users to represent the behavioral statements (be they physical, sociological and/or psychological).

The next sections discuss each phase of the preliminary conceptual model in turn, referencing the various stages of the PADM. The purpose of these sections is to provide the rationale and context for the behavioral statements' inclusion and providing guidance at the aggregate level to highlight where the user should focus his/her attention to address each of the statements when conducting life safety analyses.

3. Behavioral Statements: Stages of the PADM

The PADM [15] provides a framework that describes the information flow and decision-making that influences protective actions taken in emergencies. According to this framework, the process of decision-making begins when people witness cues from the event (see Fig. 1). Individuals may encounter only one type of cue (for example, seeing smoke) or may be presented with a variety of different cues, including environmental cues, the behavior of others, and warning messages. The introduction of these cues initiates a series of pre-decisional processes that must occur in order for the individual to perform protective actions: receiving the cue(s), paying attention to the cue(s), and then comprehending the cue(s). Once these pre-decisional processes are complete, individuals engage in a series of stages, including risk identification, risk assessment, protective action search, and finally, protective action implementation. If at any time throughout the process, they are unable to complete a stage, e.g., they require additional information, they are likely to engage in an informational needs assessment (e.g., what information do I need?), a communication needs assessment (e.g., where and how can I obtain this information?), and communication action implementation (e.g., do I need the information now?). This process ends with the implementation of a protection action, potentially (and hopefully) leading to safety.

Overall, the PADM provides a helpful framework, outlining the processes in which an individual engages in their attempt to achieve safety. However, it does not address the specifics related to building fires: i.e., the factors that would influence various stages of the process, the types of behaviors that are likely to be performed at various stages, and the nuances unique to building fires (i.e., smoke from a fire can vary by optical density as well as levels of toxicity). Hence, the need to look to the field of human behavior in fire to populate the PADM framework, making it more specific to building fire emergencies, i.e., the preliminary conceptual model with its set of behavioral statements introduced here. The behavioral statements have been compiled according to the PADM structure to refine the description of the factors that influence performance in each stage and also make the model more relevant to evacuation from fire.

The following sections further discuss each decision-making stage of the PADM, highlighting the behavioral facts that are relevant in each stage.

3.1. Behavioral Statements Pre-Decisional Processes

Before decision-making stages begin, the individual must receive, pay attention to, and comprehend the cue(s) and information provided. These are referred to as pre-decisional processes within the PADM.

The individual must receive the cue(s) to initiate the process. In a fire, people can be presented with external cues. These cues can be physical or social in nature, meaning that they arise from the physical environment or the social environment; e.g. breaking glass and actions taken by the building population, respectively. These cues can be presented alone or several at a time, depending upon the nature of the event. Physical and social cues produced in a building fire can be received by occupants through hearing (e.g., an alarm or authority warning), smelling (e.g., smoke), seeing (e.g., others running), tasting (e.g., sulfur dioxide or hydrogen chloride), and/or touching (e.g., heat). Given the nature of the situation and individual sensory capabilities, it should not be expected that all people will have access to the same external information or will perceive it in the same way [42].

Just because an individual receives a cue does not necessarily mean that he/she has paid attention to it. Therefore, the next step involves the individual paying attention to the cue(s). This pre-decisional process involves the individual cognitively registering that a cue has been received and beginning to provide the necessary attention, which leads to the last pre-decisional process, i.e., comprehension. Comprehension means understanding the information that is being conveyed. If the message uses a different language or highly technical terms, comprehension will be difficult. Comprehension also refers to the development of an accurate understanding of environmental cues. For example, will the individual understand that the smoke s/he smells is coming from a building fire rather than from burnt toast in the kitchen?[3] Comprehension is also further complicated by the frequency of false alarms with the building or complex.

Overall, many factors influence whether information is received, paid attention to, and comprehended by individuals. The behavioral statements reflect these ideas, discussing that certain factors, e.g., cue ambiguity, stress, frequent false alarms, and sensory/cognitive impairments can provide barriers to these pre-decisional processes. In the instances where these factors inhibit the completion of pre-decisional processes, it is likely that the following risk-identification and assessment processes (of the PADM) will be delayed, in turn, focusing attention primarily to the pre-evacuation time period of a building fire. The likely impact that the behavioral statements associated with pre-decisional processes have on RSET are shown in Fig. 2. All of these behavioral statements influence the pre-evacuation time performance element (of computer-based evacuation models). Figure 2 shows that hypervigilance and clear cues (behavioral statements #2 and 5) can decrease pre-evacuation time; while all others (e.g., frequent false alarms, habituation, stress, and impairments) can increase pre-evacuation time and delays.

3.2. Behavioral Statements Stages 1 and 2: Assess Situation and Risk

After the three pre-decisional processes are completed, the core of the PADM consists of a series of five questions shown in the left-hand column in Fig. 1. The main focus of this section is on Questions 1 and 2—related to the risk identification and risk assessment stages.

During *risk identification*, the individual decides if there is actually something occurring that may require his/her attention and action, sometimes referred to as warning belief [43], but referred to here as *threat belief* to account for people's reactions to all types of environmental cues [15]. If the individual's answer is yes, then the individual is said to believe the threat, and subsequently moves on to consider the next question in the process.

Next, a *risk assessment* is performed. Research has shown that a person's perception of personal risk, or anticipated personal exposure to death, injury or property damage, is highly correlated with disaster response [15]. In this stage,

[3] An individual's perception of their environment and the manner in which they may function within it is also address in Gibson's theory of affordances [32].

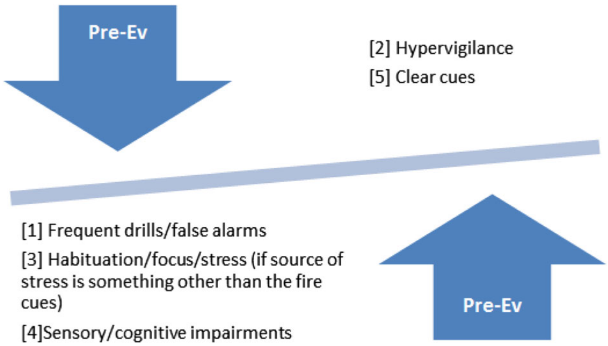

Fig. 2. Potential effect of pre-decisional processes on RSET (pre-evacuation time).

also known as personalizing risk [24], the individual determines the likelihood of personal consequences that could result from the threat and asks the following: ‘‘Do I need to take protective action?’’ Essentially, at this point, which is also discussed in human factors research as ‘‘situation awareness’’ [44], the individual tries to gain insight on the potential outcomes of the disaster and what those potential outcomes mean for his/her safety. The internal dialogue that takes place at this stage can be thought of as mental simulation or mental modeling. This involves the individual developing a mental model of what is going on in his/her environment, based on perceived cues. The individual then expands the mental model to project forward and predict the personal consequences of the event [28]. The more certain, severe, and immediate the risk is perceived to be, the more likely the individual is to perform protective actions [45].

Especially in the initial stages of an event, individuals may have difficulty with the first two questions—identifying and assessing the risk. Even after receiving what many would consider obvious evidence of danger, some people disbelieve or disregard the threat altogether—thinking that nothing unusual is happening that places them at risk, known as normalcy bias [26]. People may also think that even though there may be a threat present, it will not negatively affect them, known as optimistic or optimism bias [46]. Individuals often have trouble estimating the consequences or severity of an incident since they are likely unfamiliar with the potential speed of fire development or lethality of toxic smoke products.

On the other hand, there are factors that are more likely to increase the likelihood of individuals identifying and assessing risks. For example, if cues or information about an actual fire event are provided from a credible (and authoritative) source in a consistent manner, individuals are more likely to believe that a threat is viable. Additionally, if others around the individual are and/or seemed concerned about a possible serious fire event, the likelihood of risk identification and assessment increases.

The likely impact that the behavioral statements associated with this PADM stage have on RSET are shown in Fig. 3. All of these behavioral statements influence the pre-evacuation element. Figure 3 shows that credible cues, authoritative

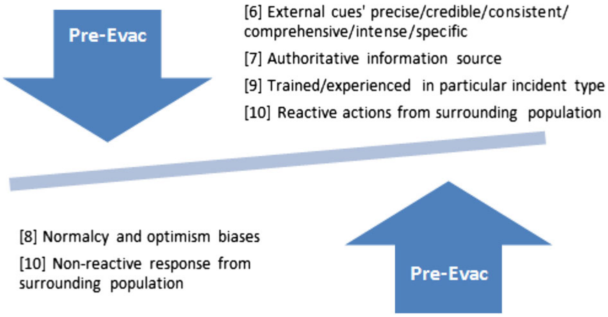

Fig. 3. Potential effect of Stages 1 and 2 on RSET (pre-evacuation time).

information sources, training/experience, and reactive actions from the surrounding population (behavioral statements #6, 7, 9, and 10) can decrease pre-evacuation time; while all others, i.e., bias and non-action from the surrounding population, can increase pre-evacuation time and delays.

3.3. Behavioral Statements Stages 3 and 4: Protective Action Search and Selection

In the next stage of the five-question process within the PADM (see Fig. 1), the individual engages in a *protective action search*, i.e. seeks options or ways to achieve protection. Research literature suggests that individuals develop their options by performing mental simulation [47, 48], similar to the methods of developing interpretations. Mental simulation [28] allows an occupant to mentally structure scenarios in the current situation, project the current situation into the future, and estimate possible outcomes. The search for options becomes the process of mentally developing scenarios of action before actually performing the act, which can be influenced by pre-event training or previous experiences in fire incidents.

The search for options of what to do can also occur collectively [49]—either collaboratively or through suggestion by a leader figure. In addition to interpreting an event, groups work together to plan a coordinated action that will solve the problem presented by the interpretation, if any. Suggestions for actions can come from any member of the group, although leaders are likely to emerge with suggestions of next actions [49, 50]. In the face of uncertainty and time pressure, people are likely to come together, share their interpretations, and define plans for collective action in an event.

Individuals or groups are unlikely to search for a large number of options during the decision-making phase. Research suggests that individuals and groups are likely to develop a narrow range of decision options due to the following conditions: (1) perceived time pressure [51–54]; (2) limited mental resources [30, 55, 56]; and/or (3) training and knowledge of procedures [28, 48]. Time pressure, likely in a fire event, causes people to perceive a fewer number of cues (termed perceptual narrowing), process the information less thoroughly and in turn, to consider a narrow set of options [51]. Also, people do not expend large amounts of intellectual resources envisioning the broad range of scenarios, but rather are likely to envision only the scenarios that they believe are necessary to reach a goal [55]. Finally, research suggests that those who are highly trained and/or know of specific procedures will be guided by training and will likely not develop more than one option at a time [28].

Following the protective action search, individuals undertake a *protective action assessment*, i.e. assess the potential option(s), evaluate the option(s) in comparison with taking no action and continuing with normal activities, and then select the best method of protective action.

Rationality-based research claims that individuals will attempt to optimize their decision-making by considering all options developed and choosing the best one—known as rational choice strategy [57, 58]. In a fire situation, weighing of multiple options is unlikely to occur. Research on decision-making under uncertainty indicates that people use a variety of heuristics to make this choice [28, 59]. Heuristics are simple rules to explain how individuals make decisions. Whereas some research might view the use of heuristics as a source of bias in decision-making [60], other researchers see heuristics as strengths based on the use of expertise [61]. Examples of heuristics that individuals employ in choosing options include anchoring or focusing on the first option developed [59], choosing the most available option (the easiest to develop or recall) [59], comparing all options with each other and choosing one based on the evaluation criteria [62–64], and satisficing [30].

Satisficing [30, 55, 65] is a method in which an individual chooses the first option that seems to work, though not necessarily the *best* option overall [28]—an option which produces results that are good enough rather than optimal. The satisficing heuristic actually combines the processes of option development and option choice together in one step. As the decision-maker develops options, s/he evaluates each one as it is developed and stops developing options when one is deemed to satisfy the search criteria. Whereas the rational choice strategy is more likely to be used when people attempt to optimize a decision [28], satisficing is more likely to be used in situations with a greater time pressure, dynamic conditions, and ill-defined goals [28].

In emergencies, individuals at risk have two general options: taking protective action or continuing previous activities. Once an action is chosen, the end result of the protective action assessment is an adaptive plan, which can vary in its specificity.

Behavioral statements 11–17 are likely to influence the search and assessment of protective actions taken by individuals in a fire event. Rather than consistently influencing a performance element (i.e., increasing or decreasing its value), the immediate impact of these statements is largely scenario-dependent. For instance, the actions of a surrounding population can influence the action selection process of an evacuee. The impact of this choice/behavior will largely depend on the suitability of the actions of the surrounding population given the conditions faced; i.e. they might help or make things worse.

3.4. Behavioral Statements Stage 5: Protective Action Implementation

According to the PADM, after a protective action is chosen and the adaptive plan is developed, individuals *may* undertake *protective action implementation* and perform the action that they decided upon in the decision-making phase. If new information is presented before an action is performed, the occupant will reconsider and may discard the current action and begin the behavioral process again. The action involves performing some type of physical act, although the act could be waiting or even inaction that takes some amount of time to complete (or is conducted for a period of time). Both summary research (e.g., [11, 34–36]) and research on specific incidents (e.g. [66–69],) highlight certain actions in which people are likely to engage [10].

These protective actions, depending upon the situation, can include waiting, alerting others, preparing for evacuation, assisting others, fighting the fire, and searching for and rescuing others. However, if information received is incomplete, ambiguous, or contradictory, causing uncertainty in understanding cues and which actions to take, individuals will likely engage in additional information-seeking actions (shown by the right-hand column in Fig. 1). These can include milling, physically seeking information, and/or asking others for information. The greater the ambiguity perceived, the more likely that individuals will search for additional information that can guide their actions [49, 70, 71]. Any information gained will then act as social or physical cues to begin the decision-making process over again.

Note that individuals do not have to go through each stage or question in the decision flow chart shown in Fig. 1. For example, if an individual is presented with information about the event from a credible source or if s/he is ordered to evacuate, s/he may move on to later stages in the decision process rather than going through each one in succession. Finally, individuals who decide that they are not at risk may neglect to take protective action at all and in turn, terminate the emergency decision-making process.

Behavioral statements 18–25 are likely to influence the actions taken by an evacuee. Similar to the previous set of statements, the immediate impact of these statements is largely scenario-dependent. For instance, the appearance of a route, including the presence of smoke as well as the presence of other people, can influence its use. Training and familiarity with a route can also influence its use. The impact (i.e., positive or negative) of these factors will largely depend on the scenario or scenarios being tested.

3.5. Behavioral Statements: General

The preliminary conceptual model (Table 1) also includes general statements that provide more of an abstract view on the nature of evacuation. For instance, behavioral statement #26 highlights "rational behavior as more likely than panic". This statement might be applicable at numerous points during a fire emergency; and therefore, applies to all of the stages of the PADM.

Similarly, the behavioral statements about evacuation being a social process and the influence of social norms apply to all stages of the evacuation process. Social processes influence actions taken in the earlier stages of an evacuation (e.g., individuals responding to cues from managers and others with recognized responsibilities or roles, thereby impacting pre-evacuation time), as well as the latter phases (e.g., individuals moving to find and form groups with others in order to exit together, thereby impacting elements such as behavioral itineraries, route usage/choice and physical movement characteristics).

Social norms may be derived from peer, organization, cultural and/or societal influences (e.g. unquestioningly following instructions issued by a manager because that is the example led by others at the organization, or because such obedience is implied in one's contract, etc.) and these existing "rules" may influence behavior during a fire. However, in a fire emergency, individuals often face new and unfamiliar situations, and are required to make a concerted effort to create meaning out of this, often under time pressure. From this meaning, a set of actions, different from those that have become routine, must be created. Emergent norm theory (ENT), explains the process of meaning-making in the face of uncertain conditions [49], stating that in situations where an event occurs that creates a normative crisis (i.e., an event where the institutionalized norms may no longer apply), individuals interact collectively to create an emergent situationally-specific set of norms to guide their future behavior. So, for instance, if a manager was not present at the time of the fire to tell employees what to do, individuals might go through milling [72] and keynoting processes [49], working together to redefine the situation and propose a new set of actions.

Even if a manager or others with responsibilities were present, they might be located in a building that is subject to frequent false alarms. This raises the question of the interaction between roles and the frequency of false alarms and their influence on situation and risk assessment. More generally, it raises the question of interactions among the behavioral statements as a whole. It will be important, in the next stage of this research, to identify the ways in which some of these factors overlap with one another and which factors are more influential than others in this decision-making process.

4. User Representation of Current Understanding

Modelling is a process that involves the user, the evacuation tool being employed and the data/theory available that supports our understanding of evacuee response in a given scenario. The user defines scenarios of interest, using the data/theory available and then represents these scenarios by configuring the evacuation tool being employed. The number and nature of these scenarios determine the scope of the analysis, the initial conditions, and the assumptions on which the evacuee response is based. As such, the 'behavioral model' is a composite of these three components. The behavioral statements might be represented explicitly or implicitly in this model—in the scenario definition, in the model configuration and/or in the manner in which the model is applied.

As noted earlier, the current set of evacuation tools do not explicitly represent all of the behavioral statements. In any scenario, all of the statements should be considered to determine the impact that they might have on evacuee performance. The final impact or relevance of these statements will be highly scenario dependent, but the statements should at least be considered to determine whether they have an impact and the extent to which they influence the results. Their inclusion or exclusion from consideration should be justified in all cases.

Broadly speaking the behavioral statements can be considered within an RSET calculation in the following ways:

1. The egress model has credible/validated functionality that is able to explicitly represent the set of behavioral statements. The user then needs to ensure that this functionality is activated. Note: this model does not currently exist.
2. The set of behavioral statements used has sufficient supporting data such that it can be represented by the user directly within the egress scenario. Depending on the data and the model, this might be employed to represent the higher-level conditions that emerge (e.g. flow) or agent-level actions (e.g. travel speeds). The user then imposes a response on the evacuating population given the derived impact of the statements on performance. This might be represented quantitatively or qualitatively, given the nature of the impact.
3. There is currently insufficient supporting data to characterize the impact of the statements. The statements might then be used to define a scenario or as part of a sensitivity analysis by varying parameters in the calculation/egress model. This would enable the impact of different parameter levels upon the results to be established without necessarily having definitive indications of what the levels might be and what the impact might be. An example of this is varying the proportion of a population that use a particular route to establish the sensitivity of the results to exit familiarity. The user is then accounting for the potential impact of a statement rather than assigning the specific impact of a statement. The modelling process is then adapted to account for this variability.
4. The set of behavioral statements cannot explicitly or implicitly be included in the configuration of the model or scenario design. Several of the statements (e.g. behavioral statements #26–28) relate to more abstract elements that influence the nature of the conceptual model rather than a specific parameter.

Where a model does not explicitly represent the impact of the behavioral statements (as is currently the case), the user may manually configure the engineering elements available—relating to pre-evacuation time, physical movement characteristics, route availability, route use and behavioral itineraries (if available)—to implicitly represent the impact of these statements. In essence, the user is augmenting the existing behavioral model. The user drives the simulated evacuees to perform in a certain manner to reflect the statements that are relevant to the scenario in question. The precise manner in which this is performed is reliant on the availability of supporting data/information and the specificity of the statements' impact. For instance, this may require quantitative changes (e.g. increasing/decreasing the assigned pre-evacuation times, travel speeds or attainable flow rates) or qualitative changes to the evacuee response (e.g. route use/availability or tasks to be performed).

As more relevant data is collected, so the quantification of the behavioral statements within fire engineering will become more commonplace, providing less of a need for the user to rely entirely on sensitivity analysis across a wide range of values.

Broadly speaking, the behavioral statements influence different performance elements (see Table 2). Where the influence is both quantitative and consistently in one direction, this is shown by an arrow, in Table 2, indicating the direction of the impact. Otherwise, the fact that it influences a performance element is simply shown as a blacked-out square, with no direction. This notation highlights the behavioural statements that are scenario-dependent and require the user to account for these statements in a way that is most relevant for the scenario(s) at hand. For instance, definitive guidance may be unavailable on the precise likelihood of an evacuee making use of a particular route. However, we can assess the likelihood of smoke spread to this route, and based upon calculations of optical density and toxic products, can make a more informed prediction on route usage. Additional information on the development of occupant scenarios can be found in a number of locations, in addition to data on human behavior in fire, which can be used to support the input of behavioral statements into occupant scenarios (e.g. [11, 73, 74]).

Table 3 presents a hypothetical scenario exploring the impact of the statements on the RSET calculation. To create this hypothetical scenario within the model, the user would likely review the behaviour statements for guidance on the critical factors to represent. Additional guidance on behavioral scenario development and supporting data can be found in the SFPE Handbook [73, 74]. Here, the model user is required to assess the evacuation of an office building. Notification is provided by a voice alarm/PA system, supported by active, trained fire marshals. The building is subject to organized, regular fire drills. The emergency procedure also ensures that non-emergency systems (e.g. computer terminals) are disabled on the sounding of the alarm.

The behavioral statements highlighted in Table 2 can be interpreted according to their impact on the egress scenario and the practicality of representing this impact; i.e., (a) where data can be found to represent the impact of the statement directly; or (b) whether the statements suggest egress scenarios or parameter variation as part of a sensitivity analysis (e.g., because there is insufficient data available and/or there are interactions among behavioral statements). Where data could be found, the effect upon the calculation has been classified as either ‘‘decrease’’, where the scenario and set of behavioral facts will likely reduce RSET or ‘‘increase’’, where the scenario and set of behavioral facts will likely increase RSET (following on from the guidance provided in Table 2). This categorisation will, in reality, be dependent on the manner in which that data were collected for the values used in the model/calculation and the extent to which the represented scenario is similar to the scenario where the data were collected.

Table 2
Representative Engineering Assumptions

	Performance Elements				
Behavioral Statement	Pre-Evac	PMC	RA	RU	BI
1	↑				
2	↓				
3	↑				
4	↑				
5	↓				
6	↓				
7	↓				
8	↑				
9	↓				
10					
11					
12					
13					
14					
15					
16					
17					
18					
19		↓			
20					
21					
22	↑				
23					
24					
25					
26					
27					
28					

5. Summary/Conclusions

Understanding and representing evacuee performance is a difficult and complicated task. This task is made even more difficult by our partial understanding of the problem at hand, further compromised by our tendency to oversimplify and focus on the physical at the expense of the psychological and the sociological. The lack of a comprehensive conceptual model of human behavior in fire has important consequences for the users of egress models in that it introduces significant

Table 3
Example Impacts of Related Sets of Behavioral Statements

Description of consideration within the scenario of interest	Related behavioral statements	Potential effect upon RSET [decrease, increase]
Training, drills, experience (pre-event)	1, 9, 11, 17, 18, 20	*May increase or decrease*: Perform sensitivity analysis of pre-evacuation times
As part of the company policy, an evacuation drill is conducted every month and the building has never experienced an actual fire event before—potentially *increasing* time to assess the risk, but *decreasing* the time to decide upon an action		
The alarm system is well-maintained to reduce the likelihood of false alarms—potentially *decreasing* the time to assess the risk		
Routine activities (pre-event)	3, 12	Decrease
Given the nature of the work in this office, people focus intently on their computer screens; however, PC terminals are shut down as part of the emergency notification process		
Occupants are assumed to not be overly committed to their tasks, since all tasks could be put on hold temporarily without harm to the buildings or others (e.g., no laboratory experiments take place in this building)		
Emergency communications and response	1, 2, 5, 6, 7, 8, 9, 10, 13, 14, 15, 16, 18, 28	Decrease
The building is equipped with a voice/PA alarm system, supported by active, trained fire marshals. The PA messages are concise, yet detailed		
Other means of information are disabled to reduce background noise		
Fire wardens are in managerial positions, and thus, are considered credible sources		
Occupants (a heterogeneous population, with different characteristics and social roles, is distributed throughout the building) are assumed to follow the guidance of these members of staff		
The building is an open plan office so occupants are likely to see and hear others evacuating—including fire wardens. *Therefore, normalcy bias and optimistic bias are reduced*		
People with disabilities	4, 5, 18, 21	Increase
6% of occupants are assumed to have sensory, cognitive, and/or physical impairments		

Table 3
continued

Description of consideration within the scenario of interest	Related behavioral statements	Potential effect upon RSET [decrease, increase]
Protective actions	16, 22, 23, 24, 26	Increase, especially for fire warden population
Occupants will likely require time to seek others out, offer help, and at the very least, gather their personal belongings		
Fire wardens will be more likely to assist others in evacuation, spend time giving instructions		
Route usage	11, 14, 18, 19, 24	Increase
All occupants only use one of the exit doors for routine usage. They are more likely to use that door during an evacuation		
Re-entry	24, 25	Decrease
All occupants are assumed to have little emotional attachment to the structure or its contents		
In addition, dedicated staff will be located at the final exits as part of the procedure to ensure that re-entry is not possible		
Social groups	27	*May increase or decrease*
Occupants will be located within teams within the building. This will assist with increasing the speed at which information of the need to evacuate is communicated. These teams are assumed to remain intact during the evacuation		

factors based on research and theory that can substantially increase or decrease evacuation times.

This article has presented a list of 28 behavioral statements, with associated suggestions made regarding how the user might represent these statements in evacuation models using the core performance elements (e.g. pre-evacuation times, physical movement characteristics, route availability, route usage, and behavioral itineraries). These behavioral statements have been derived from research in evacuations from fire, along with input from broader disasters research. Given the different foci of the original subject areas, little research, until now, has been available that links influential factors (including individual characteristics, environmental cues, and process factors, such as risk perception) to *specific* protective actions. These linkages are especially important since the focus here is to improve evacuation models and their ability to predict the performance of specific pre-evacuation actions and associated delay times.

Most current models are significant simplifications of actual evacuee response. None of the current models are able to represent all of the statements identified without significant user intervention. The embedded behavioral models are limited in scope and refinement. However, most of the models available allow the user to manipulate the basic performance elements: pre-evacuation times, route usage, route availability, physical movement characteristics and behavioral itineraries (to some extent). This provides an opportunity for these elements to be configured to represent the impact of the behavioral statements (be they sociological, psychological or physical) on evacuation performance. This discussion has examined the behavioral statements and how the user might represent them in an egress model by configuring these basic performance elements.

The authors hope that this discussion will promote further development of conceptual models in the field and their implementation within egress models in the future. This should then at least enable model users to represent key evacuee behaviors within the modelling environment without directly imposing them upon the scenario at hand.

Acknowledgments

Kuligowski would like to thank Richard Peacock, Therese McAllister, Jason Averill, and Enrico Ronchi for their contributions during the NIST review process. Gwynne would like to thank Ahmed Kashef, Cameron McCartney and Lisette Seguin for their contributions during the NRC review process.

References

1. Department for Communities and Local Government (2006) Approved Document B(fire safety), vol 1. Dwelling Houses, The Building Regulations 2010, England, UK. https://www.gov.uk/government/publications/fire-safety-approved-document-b. Accessed August 2013

2. Shook and Stone (2013) Small fire reported in the stratosphere hotel and Casino. http://www.shookandstone.com/Personal-Injury-Blog/2013/July/Small-Fire-Reported-in-the-Stratosphere-Hotel-an.aspx. Accessed July 2013
3. BuroHappold Engineering. http://www.burohappold.com/projects/project/o2-arena-and-millennium-dome-65/. Accessed June 2013
4. Durso F (2012), Upgrading liberty, NFPA journal, July/August. http://www.nfpa.org/newsandpublications/nfpa-journal/2012/july-august-2012/features/crowning-achievement. Accessed May 2012
5. Building Design + Construction (2013) Mall of America will double in size after $2.5 billion expansion. http://www.bdcnetwork.com/mall-america-will-double-size-after-25-billion-expansion. Accessed July 2013
6. Gwynne SMV, Rosenbaum ER (2009) Employing the hydraulic model in assessing emergency movement. In: DiNenno (ed) et alSFPE handbook of fire protection engineering, vol 4th. National Fire Protection Association, Quincy, pp 3–373–3–396
7. Galea ER, Lawrence PJ, Gwynne S, Filippidis L, Blackshields D, Cooney D (2011) Buildingexodus v5.0, user/technical guide, University of Greenwich
8. Kuligowski ED, Peacock RD, Hoskins BA (2010) Review of building evacuation models. 2nd edn. TechNote 1680, NIST
9. Gwynne SMV (2012) Translating behavioral theory of human response into modeling practice. NISTGCR—12-972, National Institute of Standards and Technology
10. Kuligowski ED (2011) Terror defeated: occupant sensemaking, decision-making and protective action in the 2001 World Trade Center Disaster. University of Colorado, PhD Dissertation, http://gradworks.umi.com/3453742.pdf
11. Kuligowski ED (2016) Human behavior in fire. In: Hurley MJ (ed) The SFPE handbook of fire protection engineering, 5th edn. Springer, New York, pp 2070–2114
12. Kuligowski ED (2009) The process of human behavior in fires. Technical note 1632, National Institute of Standards and Technology, Gaithersburg
13. Canter D (1980) Fires and human behaviour. Wiley, New York
14. Gwynne SMV, Hulse LM, Kinsey MJ (2015) Guidance for the model developer on representing human behavior in egress models, fire technology. Springer, New York
15. Lindell MK, Perry RW (2004) Communicating environmental risk in multiethnic communities. Sage Publications, Thousand Oaks
16. Sorensen JH, Vogt-Sorenson B (2006) Community processes: warning and evacuation. In: Rodriguez H, Quarantelli EL, Dynes RR (eds) Handbook of disaster research Springer, New York, pp 183–199
17. Mileti DS, Peek L (2001) Hazards and sustainable development in the United States. Risk Manag Int J 3(1):61–70
18. Tierney KJ, Lindell MK, Perry RW (2001) Facing the unexpected: disaster preparedness and response in the United States. Joseph Henry Press, Washington, DC
19. Drabek TE (1986) Human system responses to disaster: an inventory of sociological findings. Springer, New York
20. Mileti DS, Drabek TE, Haas JE (1975) Human systems in extreme environments: a sociological perspective. Institute of Behavioral Science, University of Colorado, Boulder
21. Proulx G, Latour JC, MacLaurin JW (1994) Housing evacuation of mixed abilities occupants. IRC-IR-661, Internal Report, Institute for Research in Construction, National Research Council of Canada
22. Bruck D (2001) The who, what, where and why of waking to fire alarms: a review. Fire Saf J 36:623–639
23. Americans with Disabilities Act of 1990-ADA-42 U.S. Code Chapter 126

24. Mileti DS, Sorensen JH (1990) Communication of emergency public warnings: a social science perspective and state-of-the-art assessment. Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge
25. Proulx G, Sime JD (1991) To prevent 'Panic' in an underground emergency: why not tell people the truth?. Fire Safety Sci 3:843–852. doi:10.3801/IAFSS.FSS.3-843
26. Okabe K, Mikami S (1982) A study on the socio-psychological effect of a false warning of the Tokai earthquake in Japan. A Paper presented at the Tenth World Congress of Sociology, Mexico City, Mexico
27. Helweg-Larsen M, Shepperd JA (2001) Do moderators of the optimistic bias affect personal or target risk estimates? A review of the literature. Personal Social Psychol Rev 5(1):74–95
28. Klein G (1999) Sources of power: how people make decisions. The MIT Press, Cambridge
29. Latane B, Darley JM (1970) The unresponsive bystander: Why doesn't he help?. Appleton-Century Crofts, New York
30. Simon HA (1956) Rational choice and the structure of environment. Psychol Rev 63(2):129–138
31. Sime J (1984) Escape behavior. In: Fire: panic' or affiliation?, PhD Thesis, Department of Psychology, University Of Surrey
32. Gibson D (1977) The theory of affordances. In: Shaw R, Bransford J (eds) Perceiving, acting, and knowing: Toward an ecological psychology, 1st edn. John Wiley & Sons, Hoboken
33. Nilsson D (2009) Exit choice in fire emergencies—influencing choice of exit with flashing lights, Lund University, Doctoral Thesis
34. Bryan JL (2002) Behavioral response to fire and smoke. In: DiNenno PJ (ed) The SFPE handbook of fire protection engineering, 3rd edn. National Fire Protection Association, Quincy, pp 3–315–3–341
35. Proulx G (2002) Movement of people: the evacuation timing. In: DiNenno PJ (ed) The SFPE handbook of fire protection engineering, 3rd edn. National Fire Protection Association, Quincy, pp 3–342–3–365
36. Tong D, Canter D (1985) The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire. Fire Saf J 9(3):257–265
37. Quarantelli EL, Dynes RR (1972) When disaster strikes (it isn't much like what you've heard and read about). Psychol Today 5:67–70
38. Fischer HW III (1998) Response to disaster: Fact versus fiction and its perpetuation, the sociology of disaster, 2nd edn. University Press of America, New York
39. Santos G, Aguirre BE (2004) Critical review of emergency evacuation simulation models. In: Peacock RD, Kuligowski ED (eds) Workshop on building occupant movement during fire emergencies National Institute of Standards and Technology, Gaithersburg, pp 27–52
40. McPhail C (1991) The myth of the madding crowd. Walter de Gruyter Inc, New York
41. Gwynne S, Galea ER, Lawrence PJ, Owen M, Filippidis L (1999) A review of the methodologies used in the computer simulation of evacuation from the built environment. Build Environ 34:741–749
42. Gwynne SMV (2007) Optimizing fire alarm notification for high risk groups. Summary Report, prepared for The Fire Protection Research Foundation, NFPA, Quincy, MA
43. Mileti DS (1974) A normative causal model analysis of disaster warning response. University of Colorado, Department of Sociology, Boulder

44. Groner N (2009) A situation awareness analysis for the use of elevators during fire emergencies. In: 4th International Symposium on Human Behaviour in Fire: Conference Proceedings. London: Interscience Communications, pp 61–72
45. Perry RW, Lindell MK, Greene MR (1981) Evacuation planning in emergency management. Lexington Books, Lexington
46. Kunreuther H (1991) A conceptual framework for managing low probability events. Center for Risk and Decision Processes, University of Pennsylvania, Philadelphia
47. Gwynne S, Galea ER, Lawrence PJ, Owen M, Filippidis L (1999) Adaptive decision-making in building EXODUS. J Appl Fire Sci 8:265–289
48. Thompson CM, Forester JA, Cooper SE, Bley DC, Wreathall J (1997) The application of ATHEANA: a technique for human error analysis. In: Proceedings of the IEEE Sixth Annual Human Factors Meeting, pp 9–13-9–17
49. Turner RH, Killian LM (1987) Collective behavior, 3rd edn. Prentice Hall Inc, Englewood Cliffs
50. Connell R (2001) Collective behavior in the September 11, 2001 evacuation of the World Trade Center. Preliminary Paper #313. University of Delaware Disaster Research Center, Newark
51. Karau SJ, Kelly JR (1992) The effects of time scarcity and time abundance on group performance quality and interaction process. J Exp Soc Psychol 28(6):542–571
52. Zakay D (1993) The impact of time perception processes on decision making under time stress. In: Svenson O, Maule AJ (eds) Time pressure and stress in human judgment and decision making Plenum Press, New York, pp 59–72
53. Janis IL (1982) Decision making under stress. In: Goldberger L, Breznitz S (eds) Handbook of stress: theoretical and clinical aspects The Free Press, New York, pp 69–87
54. Ben Zur H, Breznitz SJ (1981) The effect of time pressure on risky choice behavior. Acta Psychol 47(2):89–104
55. Gigerenzer G, Selten R (2001) Bounded rationality: the adaptive toolbox. The MIT Press, Cambridge
56. Vaughan D (1999) The dark side of organizations: mistake, misconduct, and disaster. Ann Rev Sociol 25:271–305
57. Slovic P, Fischhoff B, Lichtenstein S (1977) Behavioral decision theory. Ann Rev Psychol 28:1–39
58. Peterson CR, Beach LR (1967) Man as an intuitive statistician. Psychol Bull 68(1):29–46
59. Kahneman D, Slovic P, Tversky A (1982) Judgment under uncertainty: heuristics and biases. Cambridge University Press, New York
60. Tversky A, Kahneman D (1974) Judgment under uncertainty: heuristics and biases. Science 185:1124–1131
61. Flin R, Salas E, Strub M, Martin L (1997) Decision making under stress. Ashgate Publishing Ltd, England
62. Orasanu J, Fischer U (1997) Finding decisions in natural environments: the view from the cockpit. In: Zsambok C, Klein G (eds) Naturalistic decision making Erlbaum, Mahwah, pp 343–358
63. Janis IL, Mann L (1977) Decision making: a psychological analysis of conflict, choice, and commitment. Free Press, New York
64. Hammond KR, Adelman L (1976) Science, values, and human judgment. Science 194:389–396
65. Slovic P, Kunreuther H, White GF (1974) Decision processes, rationality, and adjustments to natural hazards. In: White GF (ed) Natural hazards Oxford University Press, New York, pp 187–205

66. Averill JD, Mileti DS, Peacock RD, Kuligowski ED, Groner N, Proulx G, Reneke PA, Nelson HE (2005) Federal Building and fire safety investigation of the World Trade Center Disaster: occupant behavior, egress, and emergency communications. Report NCSTAR 1-7. National Institute of Standards and Technology, Gaithersburg. http://wtc.nist.gov/NISTNCSTAR1-7.pdf
67. Isner MS, Klem TJ (1993) World Trade Center explosion and fire, New York, New York, February 26, 1993. Fire Investigation Report. National Fire Protection Association, Quincy
68. Bryan JL (1982) Human behavior in the MGM grand hotel fire. Fire J 76:37–48
69. Best RL (1977) Reconstruction of a tragedy: the beverly hills supper club fire. National Fire Protection Association, Quincy
70. Fahy RF, Proulx G (1997) Human behavior in the World Trade Center evacuation. In: Hasemi Y (ed) Fire safety science—Proceedings of the Fifth International Symposium. London: Interscience Communications Ltd, pp 713–724
71. Mileti DS, O'Brien PW (1992) Warnings during disasters: normalizing communicated risk. Soc Probl 39(1):40–57
72. Aguirre BE, Wenger D, Vigo G (1998) A test of the emergent norm theory of collective behavior. Sociol Forum 13(2):301–320
73. Nilsson D, Fahy R (2016) Selecting scenarios for deterministic fire safety engineering analysis: life safety for occupants. In: Hurley MJ (ed) The SFPE handbook of fire protection engineering, 5th edn. Springer, New York, pp 2047–2069
74. Gwynne SMV, Boyce KE (2016) Engineering Data. In: Hurley MJ (ed) The SFPE handbook of fire protection engineering, 5th edn. Springer, New York, pp 2429–2551